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Study of reinforced concrete building demolition methods and code requirements

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Study of Reinforced Concrete Building Demolition Methods and Code Requirements

By

Haibin Huang

A Thesis is submitted to the
College of Engineering and Mineral Resources
at West Virginia University
in partial fulfillment of the requirements
for the degree of

Master of Science
in
Civil Engineering

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Abstract

The life cycle of reinforced concrete buildings is usually 40 to 90 years. However, during this life cycle, buildings will often meet some circumstances, such as disasters, changing functions, city reconstruction, or higher demand for the residence etc.; all of these circumstances will lead to demolition or reconstruction of buildings. Moreover, many of Reinforced Concrete (RC) buildings in Asia or Europe built after World War II have been used for about 50 years or more, and now need to be rebuilt or demolished. But the current demolition methods are not safe enough, and the traditional building demolition project managing methods cannot satisfy the developments of the construction industry in future. So it is quite necessary to consummate the old building demolition regulations and working code, and also to develop more practical building demolition methods.

The research program begins from the collection of related documents, including pertinent building demolition laws, codes, working methods, project examination forms, and regulations in Europe, America, Australia, Mainland China, Japan, Hong Kong, and Taiwan. On the basis of this job, the research compares the building demolition laws and regulations between different countries, and then summarizes the building demolition methods and procedures, in order to put forward the building demolition ordinances amending opinions and compose the Common Reinforced Concrete Building Demolition Code draft for the execution of building demolition projects in Taiwan.

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Chapter I

Introduction

I. Introduction

The life cycle of reinforced concrete buildings is usually 40 to 90 years. However, during this life cycle, buildings will often meet some circumstances, such as disasters, changing functions, city reconstruction, or higher demand for the residence etc.; all of these circumstances will lead to demolition or reconstruction of buildings. Moreover, a certain part of RC buildings in Taiwan have been used for about 50 years or more, and now need to be rebuilt or demolished. But the current demolition methods are not safe enough, and the traditional building demolition project managing methods cannot satisfy the developments of the construction industry in future. So it is quite necessary to consummate the old building demolition regulations and working code, also to develop more practical building demolition methods and code requirements that are suitable for using in Taiwan.

For the above purposes, this study has taken the following approaches, which are primarily: literatures collection, documents analysis, analytical comparison, discussions, and other researching methods.

The study begins with the collection of related documents, including pertinent building demolition laws, codes, working methods, project examination forms, and keeps regulations in Europe, America, Australia, Mainland China, Japan, Hong Kong, and Taiwan. The research compares the building demolition laws and regulations between different countries, and then summarizes the building demolition methods and procedures, in order to put forward the building demolition ordinances amending opinions and compose a draft for the Common Reinforced Concrete Building Demolition Code for the execution of building demolition projects in Taiwan.

II. Background

(1) Reasons for building demolition

The building's designed using period for the wood structures is usually 20 to 30 years, for RC buildings is usually 40 to 90 years. But sometime buildings are damaged by earthquake or other disasters, so these buildings need to be demolished immediately. In fact, buildings are quite often reconstructed or remodeled during their using period; moreover, due to varieties of reasons such as deterioration of concrete, lowered building's function, and city development etc., there are a lot of examples that buildings are demolished during their durable period. Therefore, the necessity of demolition not only depends on the material and structure problems, but also is based on the factors like social, economic, living, environmental reasons more and more often.

(2) The current conditions of the demolition industry in Taiwan

The current problems existed in the buildings demolition industries in Taiwan are primarily as follows:

a) Building demolition operations are mostly based on experiences, lacking project planning:

There are no strict requirements on the professional persons' qualification on the building demolition company.

b) The unit price is too low to improve demolition technologies:

Because of the price competition, the unit price of building demolition projects is too low, which results that companies are not able to afford to introduce new working methods and technologies.

c) The current demolition methods are lacking safety requirements:

The building demolition methods in Taiwan are traditional a, mostly using machines like excavators or hand-hold breakers. Demolition workers' working safety notions are also lacking, moreover the present demolition methods do not include enough safety precautionary measures.

d) The traditional demolition methods cannot satisfy the environment protection requirements:

The old management system does not give enough considerations to the environmental protection and waste recycling.

(3) Cases of building demolition accidents in Taiwan

a) Dali Dynasty Building collapsed during demolition^[1]

The building in Taichung City was damaged and inclined in the 921 Earthquake, and it was supported only by 5 steel columns. The building was located beside a drainage system, and after several days of continuous, heavy storms, the earth became soft and the foundation below the steel columns did not have sufficient supporting force. During the demolition process, on Apr. 23, 2000, the building collapsed suddenly and fell down to a 4-story apartment opposite to it. Figure 1 shows the accident.

b) The demolition machine and its operator were buried during the demolition of a building at Taizhong County, Taiping City^[1]

On Jan. 10, 2000, when demolishing a risky building of Chengzhou Electric Co. in Taiping City, the third floor of this building collapsed suddenly because the machine sit on the beams and columns which were already damaged, and this caused the machine with its operator to slip down and buried by the messes falling from above. The operator died in the hospital later.

c) Jiayi City A'li Opera floor collapsed^[1]

In Apr. 2000, when the A'li Opera was being demolished, the forth floor collapsed suddenly, which caused two excavators to fall down. The machines operators were also injured in the accident.

Fig. 1: Dali Dynasty Building collapsed during demolition^[1]

There are more demolition project accident cases, which were recorded every year by the Taiwan government and not listed here, which causes above 300 persons' death^[2] in various kinds of occupational operations each year in the recent 10 years. And the construction accidents death are about 50% in this amount, mostly cases are falling and collapsing.

Because the working environment in the demolition projects has many potential accident factors, workers in the building demolition projects are very likely to face some hazardous situations. Most probable situations to cause accidents are: falling, objects dropping, collapsing, electric shock, dust, vibration, hazardous materials, fire, explosion, etc. The labors in demolition projects are very likely engaged in such accidents, however, the labors are usually lacking sufficient safety precaution knowledge, which in turn causes a lot of unnecessary accidents in their work.

III. Objectives of this study

With the development of economies, land resources become less and less, and the projects like old districts renewing, risky buildings rebuilding, illegal buildings demolition, and plants relocation etc., occur more and more frequently. When facing

these situations, various kinds of building demolition jobs cannot be avoided. How to prevent the damages to the surrounding properties, demolition accidents, environmental pollutions, and research suitable demolition methods for different kinds of buildings is an important research topic.

The objectives of this study research are to compare different countries' advanced demolition methods, regulations and management systems, then recommend a suitable management mechanism and a draft demolition code for the building demolition project in Taiwan in order to give references for the industry and government to handle the more and more complicated building demolition management affairs.

IV. Methods and procedures

(1) Research methods

The primary methods taken in this research are: Materials collection and study, documents analysis, analytical comparison, experts' discussion, and other researching methods.

- a)** Materials collection and study: Collect related building demolition management regulations and laws in Europe, America, Australia, P.R. China, Japan, Hong Kong and Taiwan; study these countries' current building demolition management procedures and demolition operation methods.
- b)** Documents analysis: Analyze different countries' building demolition management system, statutes, codes, managing forms, working methods and procedures.
- c)** Analytical comparison: Analytically compare the different and similar points in these countries' building demolition projects management systems and working methods.
- d)** Experts' discussion: Experts' discussion meetings with experts from industries, universities, and government were hold in Taiwan by Dr. K.Y. Chang at National Taipei University of Technology; the results of these meetings were

translated to English and compiled into this report; learns the experts' opinions and suggestions, in order to draft general RC buildings demolition code and improve the research report.

- e) Other research methods: Primarily the operational research, which is to study the safety measures, hazards precautions, traffic maintenances, waste disposal and second disaster prevention in the building demolition procedure, to devise the building demolition safety operation procedure and measures.

(2) Research procedure

The research procedure is shown in the below flowchart (Fig. 2):

Fig. 2 Research procedures

V. Research results

(1) Completed working items and results:

Recently, Taiwan's fast growing economy is accumulating more and more social wealth, and the structure of business cost is also changing. Hence, the government actively promotes disaster relief and prevention plans in Taiwan to accelerate the process of modernizing the domestic disaster relief and prevention process. As for such purpose, this research will have the following achievements:

- a)** Provide government the suggestions for strengthening management of common RC buildings demolition;
- b)** Put forward related statutes improving suggestions;
- c)** Compose the common RC buildings demolition code structure and content draft (including *Generals, Demolition Plan, Safety and Accidents Prevention Plan, Site Management Plan, Contracts Management, Emergency Situations Disposal, Public Traffics Maintenance, and Waste disposition etc.*)

(2) Contributions to national disasters prevention in Taiwan

If the above said results can be put into effect, it can be expected to reduce the number of accidents as well as the invisible losses, and its notions will also have social and economic benefits for Taiwan.

Some of the results from this study have been compiled into report in Chinese for the Architecture and Building Research Institute (ABRI) in Taiwan and was published in Dec. 2006 ^[3].

Chapter II

Literature Review

1. Different countries' building demolition management codes

(1) British

British building demolition standard (*Code of Practice for Demolition, BS 6187, 2000*)^[4] is developed from its 1982 edition, and it is a relatively complete building demolition code since its early edition. This edition of demolition code considers the recent advances in the building demolition technologies and equipments, and the new statutes regarding health, environmental protection and working safety is also taken into consideration.

This edition of British demolition code also includes contents regarding building demolition project management, demolition site analysis, project risk evaluation, building decommission procedures, environmental requirements. For the better utilization and recycling of the demolishing debris, this code considers the building deconstruction techniques. It adds the principles of exclusively working zone and safe working space for the working safety. Also, the demolition methods are updated according to the current technique advances.

(2) New Zealand

New Zealand Labor Department issued an *Approved Code of Practice for Demolition*^[5] in 1994 according to the New Zealand 1992 Labor Health and Safety statutes. This Code of Practice is mainly to provide a reference for demolition contractors, governments, workers for the practicable demolition methods and project safety precautions.

(3) United States of America

Because of not finding a federal code of building demolition, this research uses the city of San Diego as an example for illustration of the demolition

procedures and requirements in the city of United States. This city's code requires that demolishing or removing buildings or structures located in the City of San Diego should be accord with the *Information Bulletin DS-5710*^[6].

Firstly, a permit is required for the demolition/removal of all structures except those exempted per Land Development Code Section 129.0503. Before issuing such a permit, the municipal committee will ask contractors to fill some application forms such as General Application, Parcel Information Checklist, Hazardous Materials Questionnaire, Storm Water Requirements etc. Then contractors need to provide the proof of cutting services of gas, water, power, and telephone. If the building is located in a historic zone, then the project is also restricted by the related statutes. This city has detailed regulations about project insurance such as \$50,000 per person injury insurance or \$5,000 per time the properties insurance, and it also requires a project completion bond.

(4) Mainland China

Recently Mainland China pays more and more attention to the safety of demolition projects, and it issued *Buildings Demolition Safety and Technique Code* (JGJ147-2004)^[7] in 2005 by the Ministry of Building. This code's main chapters are: General Regulations, Demolition Preparations, Safety Management, Technical Management, and Other Regulations.

After the context of the code, it includes an *Explanation of Code Items* which will greatly help contractors, government, and institutes to better understand the code content. Also it helps to make up a management system with the existed laws and codes.

(5) Hong Kong

The Hong Kong *Code of Practice for Demolition of Buildings 2004*^[8] is composed by the Hong Kong Building Department, and it is based on and edited from the 1998 edition. The process incorporates many experts' opinions which

make this edition code more suitable for practical operation. The new code provides the building demolition methods and safety rules according to the related statutes. The most important parts in this code are: Demolition Plan, Demolition Accidents Precaution Measures, and Demolition Methods.

Moreover, this building demolition code contains detailed illustration of building demolition procedures and specific demolition methods as a reference.

Chapter III

Building Demolition Methods and Procedures

The choice of building demolition methods is dependent on the nature of the project, site conditions, neighboring area, and equipments. The most common method is from top to bottom, which can be used in most cases. Generally speaking, the demolition procedure should be in the reverse sequence of the building procedure.

Demolition methods could be basically divided into two kinds: breaking demolition and dismantling members. Breaking demolition is to break structural members at their original places, while the dismantling method involves cutting the building members into different kinds of shapes, then sending them to the secondary break.

1. Building Demolition Methods

Before the demolition works begin, it should have a detailed building condition evaluation. These jobs should include measurements and analysis. The choice of building demolition method should be based on the previous evaluations, fully considering the practicability, safety, economy, and environmental factors as well as the surrounding buildings, streets, lands, public facilities, etc. The procedure for choosing a demolition method is shown in the following flow chart (Fig. 3).

(1) The types of demolition methods

The types of demolition methods can be divided according to energy types (such as oil pressure, electric power, heat etc.), breaking ways (dynamic, static), and debris shape (breaking, dismantling). Usually, it is difficult to just use one method to demolish a building. Table 1 describes the types of building demolition methods.

Fig. 3: Choice of Building Demolition Methods ^[1]

Table 1: Types of Demolition Methods ^[3]

Classification		Items	Representative Methods
1	By damaging scope	Confined (partial) damage	1. crushing machine method 2. crunching method 3. cutting method 4. thematic method 5. others
		Unconfined damage	1. gravity ball method 2. jacking method 3. explosive method
2	By debris shape	Breaking	1. breaking machine method 2. crushing machine method 3. gravity ball method 4. jacking method
		Dismantling	1. breaking machine method 2. cutting method 3. thematic method 4. others
3	By energy type	Mechanical impact damage	1. hand-hold breaker method 2. breaking machine method 3. gravity ball method 4. boring method
		Oil pressure damage	1. crushing method 2. jacking method 3. rock-jack method
		Boring and cutting damage	1. Cutting method 2. Wire-sewing method 3. Core-boring method
		Expansion pressure damage	1. Static breaking chemicals 2. Gas breaking method 3. Quicklime filling method 4. Expansion chemicals

		Explosive damage	<ol style="list-style-type: none"> 1. High speed explosion 2. Low speed explosion 3. Smoothly blast
		Flame damage	<ol style="list-style-type: none"> 1. Thematic method 2. Gas cutting machine 3. Flame jetting method
		Electric power damage	<ol style="list-style-type: none"> 1. Direct heating 2. Electric heating method 3. Microwave method 4. Supersonic wave method
		Jetting damage	<ol style="list-style-type: none"> 1. Water jetting method 2. Abrasive-jet method 3. Sand-jet method
		Chemicals corrosion damage	<ol style="list-style-type: none"> 1. Chemical inject corrosion

(2) Explosive demolition

Explosive demolition can be a highly efficient building demolition method. In the US, this method has already been used in old building demolitions for many years, and is especially convenient in high-rise building demolitions. But because of the control of explosives in Taiwan, this area's research is quite limited. However, with the increase of the old buildings, growth of building's height, and development of city area, there may be a demand to use explosive methods in Taiwan for demolition projects in the future. This method has the following advantages compared to the traditional methods:

- a) Period:** Explosive demolition takes a relative short time. The larger the scale of the project, the more time it saves.
- b) Safety:** When the building is higher than five floors, other common

methods will meet a lot of difficulties. At the present time, with more and more high-rise buildings the traditional methods have limitations concerning project management and operation, while through careful design the explosive demolition can be controlled to minimize the danger factors in the building demolition projects.

c) Economy: When the project scale is relatively small, the traditional method is more economical, but when project scale becomes larger, then explosive demolition will have more economic advantages.

2. Building Demolition Procedures

Building demolition procedures should include two stages: demolition operation and waste disposal. As for the demolition operation, first it should have a demolition plan, and the plan needs to include the demolition time, working site investigation, working plan draft, and application files, etc. Then a demolition project can formally begin after the plan is approved. Figure 4 shows a flow chart of the building demolition project stages:

Fig. 4 Building demolition stage flowchart (From reference [1] with modification)

3. Building Demolition Planning

Before the demolition project begins, the contractor must have a detailed working plan so as to carry out the project effectively and safely within the limits of the budget and term. The building demolition plan should be in accordance with demolition application documents, building ownership proofs, building's layout, and forehand investigations. Therefore, the building demolition plan needs to be consulted with design institutes, government, owner and contractors.

Generally, the building demolition plan should include the following 10 items:

- (1) Design Conditions: including original and present building plans, layout and drawings;
- (2) Site Conditions: building shape, size, height, and working area;
- (3) Environmental Conditions: on-site environment and surrounding area's building and traffic conditions etc.;
- (4) Working Conditions: working methods, equipments, working time, procedures, schedule etc.;
- (5) Safety Conditions: safety measures, temporary facilities, accidents and hazards prevention;
- (6) Labor Conditions: workers' skill and number;
- (7) Traffic Conditions: heavy machine maneuver, materials transportation;
- (8) Disposal Conditions: piling area, sorting, site sanitation facilities, waste disposal;
- (9) Statute Conditions: demolition, road, hazard, noise and waste statutes;
- (10) Contract Conditions: time limit, budget, payment etc.

Besides this, in this study we also consider the building demolition under emergency conditions. Based on the researches related to emergency conditions, it summarizes the demolition flowchart in case of emergencies as follows (Figure 5):

Fig. 5 Building emergency demolition operation and safety procedure ^[1]

4. Building types' classification

If we classify the building types by some standards, it can be divided by building's usage, importance, ownership, height, structure types etc.

Usage: Building usage can be grouped by business occupancies, education, factory or industry, residence, government, assembly occupancies, and other special usages like power plant, hospital etc.

Importance: Many countries have their building classification system according to the buildings' importance, security requirements, usage and location etc.

Ownership: It can be generally divided into public buildings or private buildings. For the public buildings, it usually requires more strictly on the building decommission procedure and ownership clearance.

Height: For the RC structure buildings, they can also be separated into several types, such as super high rising buildings, high buildings, common height buildings, and low height buildings.

Structure types: The common structure types which are used in built the RC buildings are frame structure, shearing wall structure, and frame-tube structure etc.

For the demolition methods and procedures described by this research, they are only suitable to the general usage and common purpose RC buildings, such as multi-story RC residential buildings, hotels, regular office buildings, school buildings, and department stores etc.

The regular methods to demolish the RC buildings are shown in the Table 2. When the building height is about 4 floors, the crushing or breaking machine can be set on the ground. While if the building becomes higher, machines need to be put on the top of the building and the demolition should be in the sequence of floor by floor. When using gravity ball to demolish buildings, the clear space for operation between the crane and the structure being demolished shall be 50% of the height of structure, also additional space for the crane to maneuver is needed.

Table 2: Suggested Methods for Different Types of Structure ^[3]

Structure Type	Suggested Methods
RC, SRC	<ol style="list-style-type: none">1. Using the crushing machine on the ground (lower than 4 stories)2. Using the crushing machine on the top floor (higher than 4 stories)3. Using the gravity ball for common buildings (multi stories) or explosive for high-rise buildings4. Using the crushing machine and breaking machine together
Steel Structure	<ol style="list-style-type: none">1. By the method of using hand tools2. By the method of using steel members breaking machine
Timber Structure	<ol style="list-style-type: none">1. By the method of using hand tools2. By the method of using small machines

5. Example of RC building columns' demolition

For a better illustration of demolition of RC structures, this paper uses a case of knocking down of an RC structure's columns using the gravity ball as an example to demonstrate the concept.

(1) Material properties

Steel

For reinforcement bars, the model used is shown in Fig. 6. The tangent stiffness of reinforcement is calculated based on the strain from the reinforcement spring, loading status (either loading or unloading) and the previous history of steel rebars. The main advantage of this model is that it can easily take into account the effects of partial unloading without any additional complications to the analysis. Reinforcement bars are assumed to be cut, which is not realistic in some cases, after reaching 1.5 times the yield stress value.

Fig. 6 Stress-Strain curve for Steel ^[10]

Young's Modulus (E) (kN / m ²)	σ_{y1} (kN / m ²)	σ_{y2} (kN / m ²)
2.10E+08	2.40E+05	2.40E+05

Concrete

As a material modeling of concrete under compression, a compression model, as shown in Fig. 7, is adopted. In this model, the initial Young's modulus, the fracture parameter, representing the extent of the internal damage of concrete, and the compressive plastic strain are introduced to define the envelope for compressive stresses and compressive strains. Therefore, unloading and reloading can be conveniently described.

The tangent modulus is calculated according to the strain at the elastic stage. To consider the biaxial confinement effects in compression, a modified compressive strength, f_{ceq} , is calculated using Eq. (1) ^[9]. This indicates that the compressive strength associated with σ_1 and σ_2 .

$$f_{ceq} = \frac{1 + 3.65(\sigma_1/\sigma_2)}{(1 + \sigma_1/\sigma_2)^2} f_c \quad (1)$$

After the peak stress, the stiffness decreases. For concrete subjected to tension, the stiffness is assumed as the initial stiffness until reaching the cracking point. After cracking, stiffness of springs subjected to tension is set to be zero (Fig. 7).

Fig. 7 Stress-Strain curve for Concrete ^[9]

(2) RC column properties

Axial Load

The axial load capacity of a reinforced concrete column depends on the axial load capacity of the longitudinal reinforcement, as well as the axial capacity carried by the concrete. According to ACI Code, the following equation is used to assess the maximum axial load capacity, P_N , of a reinforced concrete column ^[10]:

$$P_N = 0.85f_c' (A_G - A_{SL}) + f_{YL} A_{SL} \quad (2)$$

Where the first term, $0.85f_c' (A_G - A_{ST})$ represents the axial capacity carried by the concrete and the second term, $f_{YL} A_{SL}$ represents the axial capacity carried by the longitudinal reinforcement. f_c' is the specified 28-day compressive strength of concrete (ksi), f_{YL} is the yield strength of the longitudinal reinforcement (ksi), A_G is the gross area of the column cross section, and A_{SL} is the area of the longitudinal reinforcement. The maximum axial load capacity in a column is achieved when no flexural moment is induced in a column.

Flexure Capacity

The moment or flexural capacity of a reinforced concrete column depends on the cross section of the column. Given the cross section of the shear-critical column considered in this project, the maximum moment capacity of the column can be assessed by summing the internal forces from the longitudinal reinforcement and concrete about the centroid of the column.

The following equation is derived from Figure 8 and is used to evaluate the maximum moment capacity of a reinforced concrete column, M_n ^[10]:

$$M_N = T_{S3} [(h/2) - d_{S3}] + C_C [(h/2) - (a/2)] + T_{S1} [d_{S1} - (h/2)] \quad (3)$$

$$P_n = C_C + T_{S1} + T_{S2} + T_{S3}$$

Where T_{Si} is the compressive/tensile force provided by the longitudinal reinforcement i , C_C is the compressive force of the concrete, h is cross section depth, a is depth of stress block, and d_{Si} is the distance from extreme compression side of column to the reinforcement layer i . The maximum moment capacity of a column can only be reached if there are no axial loads applied to the column.

Figure 8: Cross section analysis used to compute the moment capacity of a reinforced concrete column. ^[10]

Shear

The total shear capacity of a reinforced concrete column depends on the shear capacity of the concrete, V_C and the shear capacity carried by the transverse reinforcement, V_{ST} . According to the ACI Code, the following equation is used to assess the maximum shear capacity, V_N of a reinforced concrete column subjected to combined shear, moment and axial compression loading^[10]:

$$V_N = V_C + V_{ST} = 2[1 + (N_u / [2000A_G])] \sqrt{f'_c} b_w d + (A_{ST} f_{YT} d) / s \quad (4)$$

Where N_u is the applied factor axial load, b_w is the width of the column cross section, A_G is the column section gross area, s is the transverse reinforcement spacing, d is the distance from extreme compression fiber to farthest tensile reinforcement, A_{ST} is the area of the transverse reinforcement, and f_{YT} is the yield strength of the transverse reinforcement.

Flexural Deformation

For a column that is fixed against rotation at both ends, flexural deformation results when a moment load is induced in the column and a lateral displacement occurs at the ends since there are no end restraints against horizontal displacement. Figure 9 exhibits this concept.

Figure 9: Flexural deformation in a column ^[11]

The following empirical equation, presented in Elwood and Moehle (2003), is used to estimate the lateral displacement due to flexure before yielding of the longitudinal reinforcement occurs ^[11]:

$$\Delta F_L = L^2 \Phi_Y / 6 \quad (5)$$

Where L is the column length and Φ_Y is the column curvature at yielding of the longitudinal reinforcement.

(3) Reinforced Concrete Building Frames

In general, reinforced concrete structures are designed to be durable, serviceable, and attractive. Structural elements composing a reinforced concrete system may be broadly classified into floor slabs, beams, columns, walls, and foundations.

Columns

Columns are typically vertical elements that support the structural floor and beam systems. Columns are to be subjected to both axial compressive loads and bending moments.

There are many different kinds of columns: circular and square concrete sections with a steel tubing on the outside, circular and square spiral columns with steel reinforcement, and rectangular tied columns with steel reinforcement. Rectangular tied columns are common in construction of reinforced concrete building and are used in the case presented in this study.

Column Strength Interaction Diagram

A column interaction diagram is used to determine the capacity and suitability of a column. To obtain a representation of the interaction diagram, important transitional points on the diagram are computed and connected using linear relationships. The strength capacity of the column is compared to the applied loading and moment. If the applied axial force and bending moment fall inside of the interaction diagram, the capacity of the column is satisfactory. Fig. 10 illustrates the shape and form of the beam-column strength interaction diagram.

Fig. 10 Column strength interaction diagram ^[10]

The rectilinear approximation of the strength interaction diagram has three specific regions: the maximum axial compression region permitted by the ACI Code, the compression failure region, and the tension failure region. The maximum axial compression permitted by the ACI Code (2005), $P_{n(max)}$, is $0.8P_0$ for tied columns where P_0 = nominal axial load strength at zero eccentricity. The compression failure region is delineated from the tension failure region by the balanced strain condition (M_b , P_b). Within the compression failure region an immediate point is computed midway between P_b and $0.8P_0$. The tensile failure region consists of two portions. The upper portion is bounded by the balanced condition with $\phi = 0.65$. In lower portion of the tension failure region, the strength reduction factor varies $0.65 \leq \phi \leq 0.9$ with a lower bound of zero axial capacity and steel yielding $\epsilon_t \geq 0.005$.

(4) Using Gravity ball to knock down RC column

As for the reinforced concrete building demolition methods, in reality there are lots of methods which can be selected. This research uses the gravity ball

method, which is described in many countries' demolition code, to make an approximate calculation for an example.

There are two ways of using gravity ball to demolish a building:

Fig.11 Gravity Ball Demolition Method 1^[8]

Fig.12 Gravity Ball Demolition Method 2 ^[8]

Using Fig. 8 column as an illustration, and if the demolition uses swing in-line method, the ball is drawn away from the building column by l_1 feet, the swing rope is l_2 feet, assuming the hoist hinge is in the same vertical plane as the building columns (Figure 13 shows the detail of the steel ball hitting the RC column), then:

The height that the ball being hung up is,

$$H = l_2 - \sqrt{l_2^2 - l_1^2} \quad (6)$$

The energy the gravity ball has is,

$$E = mgH \quad (7)$$

Where the m is mass of gravity ball, g is gravity acceleration, and H is the

height that the gravity ball being hung up by drawing the horizontal rope.

Fig. 13 Illustration of Swing In-line Method, Fix-Fix End

The velocity when the ball hits columns is,

$$v = \sqrt{2E/m} = \sqrt{2gH} \quad (8)$$

The momentum that will apply on column is,

$$F \cdot T_0 = m \cdot v, F = m \cdot v / T_0 \quad (9)$$

*: Here we use rectangular loading shape function; if we assume other loading shape function, then the maximum hitting force will be larger than the above equation. For example, when using a loading function same as the Hanning function, the maximum amplitude of the hitting force will be twice of the above equation.

However, the duration of impact is not easy to measure, but it can be assumed to be in a very short time period, such as 0.002 second.

We can use Hertzian contact assumptions; the impact duration can be

calculated from the following equations^[12] (Chen, etc., 1988):

$$T_0 = 2.94(5m/4n)^{2/5} / (2gH)^{1/5} \quad (10)$$

And here n is:

$$n = \frac{4/3R_b^{1/2}}{(1-\nu_b^2)/E_b + (1-\nu_c^2)/E_c} \quad (11)$$

Where R_b is the radius of the ball; ν_b , ν_c , are Poisson's ration for steel ball and concrete which are assumed 0.3 and 0.15, respectively. And E_b , E_c are Young's moduli of steel ball and concrete which is 29,000,000 psi (200GPa) and 4,000,000 psi (27.6GPa), respectively.

The following table shows the time period for choosing different radius of steel ball to hit the RC column.

Table 3: Contact duration for different size of steel balls

Radius (m)	Mass (Kg)	Drawing height (m)	Velocity (m/s)	Contact duration (msec)
0.2	148	0.5	3.13	1.24
0.2	148	1.0	4.43	1.08
0.3	499	0.5	3.13	1.86
0.3	499	1.0	4.43	1.62
0.4	1184	0.5	3.13	2.48
0.4	1184	1.0	4.43	2.16

Hence, to knock down a reinforced concrete column, the force to hit the column should be greater than the column's shear and/or moment capacity, which means:

$$F \geq V_N = V_C + V_{ST} = 2[1 + (N_u / [2000A_G])] \sqrt{f_c} b_w d + (A_{ST} f_{YT} d) / s$$

Or assume the ball hits in the middle of the column, then:

$$F*L/8 \geq M_N = T_{S3} [(h/2)-d_{S3}] + C_c [(h/2)-(a/2)] + T_{S1} [d_{S1}-(h/2)]$$

Here, we can deduce that the mass of the gravity ball should greater than:

$$m \geq T_0 * V_N / v = T_0 * V_N / \sqrt{2E/m} = T_0 * V_N / \sqrt{2gH}$$

$$\text{Or, } m \geq 8 T_0 * M_N / (v * L) = 8 T_0 * M_N / (L * \sqrt{2gH})$$

So mass of the steel ball is chosen for which one is smaller.

Use Fig. 8 column, assuming column width b and h are both 50cm, and height L is 3m; the longitude rebars are 8 #9 rebars which A_s is 6.45cm^2 each; transverse reinforcement is #4 rectangular ties @ 20cm center to center, which A_{st} is 1.29cm^2 . The clear cover for reinforcement is 4cm, so the distance to the center of longitudinal rebar is 43.3cm. Choosing concrete strength 5000psi, which is 34,474kPa; and steel strength 60ksi, which is 413,685kPa.

Table 4: Column's Shear and Flexure Capacities

A_G (m^2)	P_N (KN)	$V_N(N_u=0.8 P_N)$ (KN)	$V_N(N_u=0.7 P_N)$ (KN)	$V_N(N_u=0.6 P_N)$ (KN)	M_N
0.25	9309	1394	1244	1094	Calculated as follows

Table 5: Calculation of Column's Flexure Capacity

Pure Bending:

f_y (kPa)	ϵ_{cu}	T_{S1} (KN)	c (cm)	T_{S2} (KN)	T_{S3} (KN)	C_c (KN)	M_N (KN*m)
413685 (60ksi)	0.003	800.5	8.92	533.7	-288.9	-1045.7	423.5

$$800.5 + 0.003((25 - c)/c) * 200\text{Gpa} * 6.45 * 2 / 10000 = 0.85 * 34474 * c * 0.8 * 0.5 / 100 + 0.003((c - 6.7)/c) * 6.45 * 3 / 10000 * 200\text{Gpa}$$

$c = 11.13\text{cm}$, so T_{s2} yield.

Balanced Condition:

Where $\varepsilon_t = 0.002$ and $\varepsilon_c = 0.003$, because $h = 50\text{cm}$, $d_{s1} = 43.3\text{cm}$, we can find that:

$c = 26.0\text{cm}$, $\varepsilon_{t1} = 0.002$, $\varepsilon_{t2} = 0.00012$, $\varepsilon_{t3} = 0.0029$ (yielded), $a = 0.8 * c = 20.8\text{cm}$

f_{s1} (kPa)	ε_{cu}	T_{s1} (KN)	c (cm)	T_{s2} (KN)	T_{s3} (KN)	C_c (KN)	M_N (KN*m)	P_N (KN)
399896 (58ksi)	0.003	774	26	-31	-800.5	-3047.5	733.1	-3105

Hence, for the conservative consideration:

$$m \geq T_0 * V_N / v = T_0 * 1394\text{KN} / v$$

$$\text{or } m \geq 8 T_0 * M_N / (v * L) = 8 T_0 * 733.1\text{KN*m} / (v * L)$$

From above calculation, we know that the hitting duration is about 0.002sec and the velocity is about 4m/sec. Also, the column height is usually 3m. So,

The steel ball mass for conquering the column's shear capacity is 697kg;

And the steel ball mass for conquering the column's flexure capacity is 977kg.

Chapter IV

Discussion of Demolition Management System in Taiwan

During this study, it is found that a complete management system is one of important measures to organize projects and prevent accidents, casualties or property loss in building demolition projects. Hence, the developed countries have put the same weight on the project management as into the improvement of technology. Generally speaking, the common ways to perform demolition project management are through statutes, regulations, codes, trainings, and quality examinations etc.

1. Introduction of Building Demolition Management System in Taiwan

Recently, the city areas in Taiwan developed very fast; a lot of buildings are being renovated or reconstructed. Building demolition, as a part of the construction process, needs better techniques and management methods. The present building demolition managing modes can be divided into two categories: building codes and building statutes. Following is the explanation of the present management system in Taiwan.

(1) Present building demolition codes

The current code was composed by the Executive Yuan Public Works Committee in 2005. It contains the Chapter 02220 “Building Site Demolition”, the Chapter 0222A “Structures Demolition” and 0174A “Wastes Management and Disposal”^[13]. And it is the code which the government and contractors follow during the demolition operations.

However, this demolition code’s regulations are somewhat simplified. Generally, the Public Works Committee’s building demolition code (0222A^[23], 0174A^[24]) refers to the contents and structure of Canada National Master Specification (NMS 02 41 16, 2005^[14]). And it contains four chapters, which are “Generals”, “Products”, “Operations”, and “Quantity and Price.”

a) Generals: this chapter describes the working scope, related regulation chapters and standards, definitions, documents, and waste management etc;

- b) Products: this chapter doesn't have content;
- c) Operations: this chapter explains the safety precaution measures, preparations, safety regulations, principles in the operation, and wastes storage and disposal etc;
- d) Quantity and Price: this chapter explains the methods for calculating working items' quantity and price.

2. The Related Statutes

During the study of building laws and regulations in Taiwan, it is discovered that there are a number of statutes relating to building demolition projects; moreover, different cities have its different regulations. There are no major conflicts between these regulations. Meanwhile there is no independent law to specifically deal with building demolition works. After analyzing the present laws, this research thinks these laws can be divided into several types, such as building management, environment, safety and hygiene, and wastes disposal.

(1) Building Management Statutes:

The most important law in the series of statutes is the present *Building Law* ^[15]; it is the basis of implementing building management, including application, supervision and checking etc. Demolition is a part of construction process, so it is naturally under the Building Law's administration and needs to obey the regulations in the *Building Law*. Besides, many cities have their own regulations according to different local situations, but these regulations use the principles in the Building Law.

(2) Environment and Sanitation Statutes:

At present, Taiwan has several statutes managing the construction projects' environmental affairs. Some of them are related to building demolition projects. The following table lists these environmental laws for the demolition projects.

**Table 6: Environment and Sanitation Statutes Related with
Demolition Works** ^{[16] [17] [18] [19] [20]}

Name	Contents
Wastes Cleaning Law	The agencies, designed areas, authorities, departments and regulations etc. about the common or industrial wastes.
Standard of the Industrial Waste Storage and Disposal Methods / Facilities	Regulations about setup and operation of industrial wastes cleaning agencies, wastes cleaning and recycling regulations.
Construction Wastes Recycling Management	Origin and usage of construction wastes; Qualification, equipments, abilities, methods and standards for cleaning or recycling companies.
Noise Control Law	The locations, projects nature, facilities, standards, measuring methods for projects' noise control.
Standard for Safety and Sanitation of Construction Works	Safety and sanitation regulation for demolition projects. (Chapter 11)

(3) Labor Safety and Hygiene Statutes:

The building demolition works are also restricted by the *Labor Safety and Hygiene Law* ^[21]. The *Labor Safety and Hygiene Law* stipulates the equipment and facilities which employers need to provide for the laborers, the measures which contractors or subcontractors need to take during the demolition operation, and supervision systems need to be adopted by government or consulting agencies. All these requirements are to make sure that the safety of the workers involved in the demolishing works is considered.

3. Suggestions to the improvement of building demolition management in Taiwan

With the process of urbanization, old building demolition or reconstruction projects increase, and building demolition is becoming an important market in Taiwan. But in the current consideration, the demolition operation is part of construction procedure; the government usually does not pay enough attention to such kind of projects, which will be usually too late when accidents happens during the demolition.

The demolition project management system should be a combination of building statutes or laws, demolition codes, contractors' self-discipline behavior, project contract management, and government's administration. Currently, the building demolition market in Taiwan is growing up and becoming more mature. Based on comparison and summary, this study makes some suggestions on the management of demolition projects.

(1) Pre-bidding qualification management

This is an important stage of demolition projects management, and it is the government's duty to manage the building demolition industry.

I. The contractor for a particular project should have relevant qualification, and the government should prohibit illegally sub-contracting.

II. The demolition project should have information recording and backup requirements. The contractor should prepare the qualification document, project and surrounding building description, demolition plan, and waste disposal methods.

(2) Pre-demolition management

I. The contractor should design the building demolition plan beforehand, which needs to include demolition procedure, safety measures etc.

II. The contractor should arrange the safety training for its working staff, and

the project manager needs to make instructions to the working labors about the detailed operation regulations.

III. For the buildings containing hazardous materials, the fire department and safety department need to join together to conduct the building inspection, and the project should have a safety proposal.

(3) During-demolition management

The contractor and government both have their own duties in this stage.

I. The government needs to supervise the demolition projects in its own administrative area, check the project contract and demolition plan.

II. The contractor should execute the project exactly according to the proposed plan, and qualified professional engineers need to be always on site. The contractor must inspect its project from time to time and correct mistakes in time.

(4) Completion of demolition

I. Building demolition waste need to be stored in a reasonable manner. For the valued waste, it should be sorted to make recycle or reuse easily.

II. After completion, the project site also needs to be kept safely.

III. The building demolition project needs to arrange the completion acceptance procedure; if necessary, the contractor needs to submit the project completion bond.

Chapter V

Comparison between Different Countries

Through the study of Taiwan's current building demolition code and regulations, knowing that the main contents are concentrated in the two chapters of "Generals" and "Operation" in the current demolition code, and the whole code's structure and content still needs to be improved. Therefore, this study will describe the characters of other countries' building demolition codes in order to make a comparison.

1. Comparison with the British Code

The structure of the British Building Demolition Code (BS 6187) ^[4] is shown on the following flow chart (Fig. 14). It shows that Britain has a much more complete building code structure and contents; also this code (BS 6187) refers to many other British codes, which can be seen in the following table (Table 6).

Table 7: A series of codes related with building demolition works in Britain ^[4]

Code number	Code Name
BS 5228	Noise and vibration control on construction and open site
BS 5607	Code of practice for safe use of explosives in the construction industry
BS 5837	Guide for trees in relation to construction
BS 5974	Code of practice for temporary installed suspended scaffolds and access equipment
BS 5975	Code of practice for falsework
BS 6399-2	Code of practice for wind loads
BS 6472	Guide to evaluation of human exposure to vibration in buildings
BS 7121	Code of practice for safe use of cranes

Fig. 14 Outline of the British Code ^[4]

And similar to this, the statute system used in the British building demolition code is illustrated in the Table 7 below. Moreover, the British building demolition code has more complete and detailed contents than the Taiwan code, especially in the aspect of “Project Preparation”, “Site Conditions”, “Environment Protection”, and “Safety and Health”. But it does not contain updated information about resources reusing or recycling, so it has limits on this area in the current trend of environmental protection and resource saving.

Table 8: The Statutes Managing the Building Demolition Works in Britain ^[4]

Statute Type	Statute Name
1. Generals	Control of Major Accident Hazards Regulation 1999
2. Permission	Town and Country Planning Act 1990 Building Act 1984 Highways Acts 1980 Party Wall etc. Act 1996 New Roads and Street Works Act 1991 Etc.
3. Building Management	Building Act 1984
4. Disputes Solving	Party Wall etc. Act 1996
5. Traffic	The Road Traffic Act 1991
6. Utilities	New Roads and Street Works Act 1991
7. Insurance	Some Regulations
8. Environment	Environmental Protection Act 1990 Special Waste Regulations 1996

9. Occupational Safety and Health	The Health and Safety at Work ect. Act 1974 The Construction Regulations 1994 The Provision and Use of Work Equipment Regulations 1998 The Control of Substances Hazardous to Health Regulations 1999
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2. Comparison with the New Zealand Code

Compared with the domestic building demolition code, the New Zealand Code's structure and contents are more like the British code. This code is composed by several chapters such as "Introduction and Legislative Requirements", "Definition", "Generals", "Pre-demolition Checking", "Safety Measures", "Methods", "Equipments and Operation Safety", and "Site Pollution Cleaning". Also, as a standard of the demolition project operation and management, it has clear regulations about the responsibilities of every party in the building demolition works. The Taiwan code does not include such content, which could cause confusion in the project management. Table 8 summarizes these regulations^[2].

Table 9: Each Party's Responsibilities in New Zealand Code ^[5]

Parties	Responsibilities
1. Project Owner	<ul style="list-style-type: none"> 1. Provide all the related documents about the building to be demolished; 2. Get permission from government; 3. Make clear the working scope; 4. Notify the owners in neighbor area.
2. Contractor or Employer	<ul style="list-style-type: none"> 1. Plan for the demolition project, and choose working method; 2. Inform the owner about working method and equipments; 3. Get the working permission; 4. Check near buildings' situation; 5. Maintain safety on the site.
3. Labor or Employee	<ul style="list-style-type: none"> 1. Ensure one self's safe and health; 2. Make sure other person's safety. 3. But these will not reduce the owner's or contractor's responsibilities.
4. Government Personnel	<ul style="list-style-type: none"> 1. Help the contractor improve the project's safety; 2. Check the project with the regulations of related laws; 3. Take any necessary measures to ensure the implementation of the related statutes; 4. Any other functions given by laws.

This is the part which is clearer in New Zealand code than in other country's code. It will help the drafting of the contract, definition of responsibilities, and strengthen the project management.

3. Comparison with the Hong Kong Code

The structure of the Hong Kong code ^[8] could be roughly divided into the following parts: "Demolition Planning", "Precaution Measures", "Building Demolition Methods", "Special Structures", and "Project Supervision and Examination".

It is found that the Hong Kong code has the most detailed illustration of demolition methods, which also includes figure illustrations and specific demolition case study. Thus, this code can provide detailed reference to the choice of demolition method.

In addition, although this code has relatively brief regulations in the building environmental factors, it has some explanations about building waste and debris disposal, which primarily are regulations about waste dumping chutes, dust suppression, debris piling, waste management and disposal, and waste reuse or recycling.

4. Comprehensive comparison with different countries' regulations

After carefully studying of the different countries' building demolition code, this study presents some detailed comparisons in different aspects of demolition project management in Tables 9 through 13.

Table 10: Comparative analysis of building demolition application management

	Demolition Application Management		
	Application Process	Forms	Regulations
US (City of San Diego)	1.Power and gas cutoff certification 2.Telephone cutoff certification 3.Harbor area demolition permit 4.Special area requirements 5.Historic zone checking 6.Asbestos disposal 7.Guarantee and insurance	1.General application DS-3032 2.Building information DS-302 3.Hazard materials DS-3163 4.Storm water draining investigation	1.Land Development Law 129.0501 2.California Building Law 3.Buidling and Demolition Wastes Disposal and Recycling Requirements
British	1.Applicator information (*1) 2.Project location 3.Project descriptions 4.Additional explanation 5.Drawings submit 6.Ownership clearance	Building Permission Application (Swindon Borough Council)	1.City Planning Law 1990 2.Building Law 1984 3.Road Law 1980 4.New Road Works Law 1991 5.Party Walls Law 1996
Japan	No information temporarily	1.Large scale building demolition hazard prevention site investigation 2.Demolition permission application 3.Waster water discharge application 4.Building demolition plan 5.Building with asbestos demolition plan	1.Labor Safety Law 2.Building Law 3.Buiding Waste Recycling Law
New Zealand	1.Building information collection (*2) 2.Application information memorandum 3.Demolition plan and code preparation 4.Supervisory personnel setting 5.Permission application 6.Supplemental documents	Building Permission Application / Project Information Memorandum BA2	1.Building Law 1991 2.Building Regulations 1992 3.Occupational Health and Safety Law 1992 4.Resource Management Law 1991 5.Historic Zone Law 1980
Hong Kong	1.Demoliton plan and structure stability report 2.Site safety supervision plan 3.Technician name list 4.Equipments and operators list 5.Waste disposal and management details 6.On-site engineers name list	1.Application for building office of drawings and documents BIC-1 (*3) 2.Contractractor Appointment BA-10 3.Supervisor Appointment BA-20 etc.	1.Building Law CAP 123 2.Environmental Laws 3.Labor Department Regulations 4.Temporary Structures Design Standards 5.Other Regulations

Mainland China	1.Contractor qualification proof 2.Project and surrounding buildings description 3.Building drawing and documents 4.Project and safety plan 5.Waste storage and disposal measures	Building Demolition Permission Application Etc.	1.Building Law 2.Industry Safety Law 3.Building Project Safety Management Regulation 4.Injure Insurance Regulation
Taiwan	1.Registration (*4) 2.Examination 3.Accept or return 4.Judgement 5.Approval	1.Demolition License Application 2.Application Examination 3.Applicant Scroll 4.Building Demolition Approval 5.Illegal Building Self Demolition Agreement	1.Building Law 2.Building Technique Regulations 3.Construction Safety and Health Facilities Standards 4.Wastes Disposal Law 5.Labor Safety and Health Law

(*1): <http://www.swindon.gov.uk/pdforms-listedbuildingconservationareaconsent.pdf>

(*2): www.ccc.govt.nz/Building/buildapprvlproc.asp

(*3): <http://www.bd.gov.hk/english/forms/>

(*4): http://www.construction.tpc.gov.tw/tpc/county/gungwu/f_convenient/reminder

Table 11: Comparative analysis of building demolition project planning and safety measures

	Demolition Planning	Safety Measures
British	<ol style="list-style-type: none"> 1.Valid project site information 2.Accordance with related laws 3.Project managerial arrangement 4.Public protection measures 5.Analysis of structural stability 6.Consideration of environmental factors 7.Labor health and safety 8.Weather forecast 	<p>Structural factors:</p> <ol style="list-style-type: none"> 1.Acknowledge the structure type and characters 2.Analyze current condition of structure <p>Personnel safety and health:</p> <ol style="list-style-type: none"> 1.Consult with related agency 2.Project site safety 3.Workers safety equipment 4.Emergency procedure 5.Working permission procedure 6.Combustible or electrical dangers 7.Confined space 8.Working lonely 9.Welfare and first aid 10.Noise and vibration 11.Falling 12.Entrance and working zone
US (City of San Diego)	Project planning requirements mostly reflect in this city or State of California's Land Development Code, demolition project application and plan need to be accordance with this code's requirement (129.0505).	<ol style="list-style-type: none"> 1.Regulation for buildings containing asbestos 2.Regulation for building higher than 36 foot 3.Project property and personnel insurance 4.Pre-project checking 5.Pedestrians protection 6.Sewer cap inspection 7.Completion examination
Japan	No information temporarily	<ol style="list-style-type: none"> 1.Operation methods and sequence 2.Machine types and usage 3.Spare plan, operation area setup 4.Inform all working stuff 5.Site manpower management 6.Weather factor 7.Project manager choice and duty 8.Safety equipment

New Zealand	<p>Primarily pre-demolition checking:</p> <ol style="list-style-type: none"> 1.On-site inspection 2.Dangerous structure 3.Building structure inspection 4.Wells and underground storages 5.Demolition plan (method statement) 	<ol style="list-style-type: none"> 1.Avoid the collapse by the wind, vibration and earthquake 2.Qulified supervisors 3.Machine, tool and site security 4.Personal protection equipment 5.Public protection 6.Site entrance control 7.Noise and dust control 8.Demolittion process execution
Hong Kong	<ol style="list-style-type: none"> 1.Building appraisal and demolition plan 2.Building and building structure investigation 3.Utilities cutoff and maintenance 4.Hazardous materials (asbestos and pollutants) 	<ol style="list-style-type: none"> 1.Cover and aisle 2.Scaffold and covering curtain 3.Falling object protection shield 4.Temporary support 5.Properties protection 6.Traffic maintenance 7.Special safety considerations (Training, maintenance and occupational health etc.) 8.Environmental protection 9.Waste disposal
Mainland China	<ol style="list-style-type: none"> 1.Draft demolition contract and safety agreement 2.Project contracting qualification 3.Document submit and project information 4.Pipes cut off and move 5.Neighbour buildings protection 6.Predemolition check and emergency plan 	<p>China building demolition code describes the safety measure by the demolition types:</p> <ol style="list-style-type: none"> 1.Manpower demolition 2.Machine demolition 3.Explosive demolition 4.Static breaking demolition <p>Also, it includes brief description of demolition project general safety precaution measures</p>
Taiwan	<ol style="list-style-type: none"> 1.Documents submit 2.Coordinate pipes owners to instruct demolition 3.Partial demolition procedure and safety requirements 4.Waste water disposal 	<ol style="list-style-type: none"> 1.Neighbour facilities and properties protection 2.Supervise building condition on time 3.Maintain useful facilities 4.Site fence 5.Explosion safety regulations

Table 12: Comparative analysis of building demolition projects environmental protection measures

	UK	San Diego US	Japan	New Zealand	Hong Kong	Mainland * China	Taiwan
Planning	O	X	X	X	X	X	△
Waste sorting	O	X	X	X	X	X	X
Waste reduction, reuse and recycle	O	△	O	△	O	X	O
Environmental Laws	O	O	O	X	O	X	O
Licenses	O	X	X	X	X	X	X
Carrier registration	O	X	X	X	X	X	X
Noise and vibration	O	X	△	O	O	X	△
Air pollution control	O	X	O	△	O	X	△
Earth pollution control	O	X	X	X	X	X	X
Water pollution control	O	X	O	X	O	X	O
Special waste	O	△	△	X	O	X	X
Hazardous material investigation	X	O	△	X	X	X	△
Fire precaution	X	X	O	O	X	X	X
Plant protection	O	X	X	X	X	X	O

O has some regulations

X no regulations

△ regulations are not very clear

* The China demolition code collected in this report is a project safety code, so it does not include environmental considerations.

Table 13: Comparative analysis of building demolition labor safety protection

	UK	San Diego* US	Japan	New Zealand	Hong Kong	Mainland China	Taiwan
Personal safety equipments	O	△	O	O	△	O	O
Emergency procedure	O	X	X	X	X	O	X
Working permission	O	O	X	X	X	X	X
Utilities and combustible material	O	O	X	O	O	O	O
Flooding hazard	O	X	X	X	X	X	X
Confined space and gas	O	△	X	X	△	X	X
Lone working criteria	O	X	X	X	X	X	X
Welfare and first aid	O	X	X	X	△	X	X
Noise and vibration	O	X	X	O	△	X	X
Falling	O	X	O	O	X	△	O
Safe passage and work zone	O	△	O	O	△	O	O
Insurance	X	O	X	X	X	O	X
Project manager qualification and duty	X	O	O	O	△	O	O
Scaffold	X	X	X	O	X	O	△
Training	X	△	X	X	O	O	X

O has some regulations

X no regulations

△ regulations are not very clear

* California statutes are also suitable to City of San Diego. <http://clerkdoc.sannet.gov/Website/mc/mc.html>

Table 14: Comprehensive Comparison between Different Countries' Codes

Countries	Differences in its codes
1. British	British building demolition has a relatively complete system; it not only includes demolition project's principle and technique, but also considers administrative systems. First, it summaries the related building laws about demolition project; Second, as one of the British Codes, it refers to a lot of regulations in the other building code; besides, it is one of most detailed demolition code, which has specific content regarding the environment protection, site conditions, project preparations and even more complete content in the safety. Therefore, this code's items, definition, and structure are referred by many other countries.
2. New Zealand	New Zealand Labor Department's 1994 edition of demolition code is primarily to provide the operation and safety reference for building demolition project contractors and labors. Similar to the British Code's Structure, this code of practice is composed by the chapters as "Introductions and Legislative requirements", "Definition", "Generals", "Pre-demolition Checking", "Safety Measures", "Demolition Methods", "Equipment Using Safety", and "Site Pollution Cleaning". As the standard of project operation, New Zealand has clear regulation about the responsibilities of every participant in the project, which will assist in drafting project contracts, establishing each one's right and duty, and performing project management.
3. Japan	Japan's building demolition regulation is based on its building laws and statutes ^[22] , and it pays lots of attention to the building wastes reductions, recycling, and reusing. At same time, Japan proposes the Statute of Building Wastes in 2000, in order to promote the goal of "cycling society".

4. Mainland China	<p>Mainland China's building demolition code (JGJ147-2004)^[7] mostly considers the safety factors in the demolition projects. And its content is compendious, which consists of generals, preparations, operation safety management, safety techniques management, and other operations management. Moreover, for the better understanding and executing its regulations, it also includes the code items explanations, which will further supplement the code's content and improve the execution of the specific code item.</p>
5. San Diego, US	<p>The city of San Diego, US, manages its demolition projects in the following aspects: building demolition license application; license application censoring; time limit of demolition license; building pre-demolition checking; dangerous material disposal (such as asbestos etc.); personnel safety precautions; waste disposal; sewer cap protection; and project completion checking. The projects located in the city of San Diego need to follow the procedures in the Bulletin DS5710^[3]. This legislation requires the project insurance, project completion bond and detailed measures to protect relics.</p>
6. Hong Kong	<p>Hong Kong territory's building demolition code structure could be divided into the following aspects: demolition planning; project safety protection measures; demolition methods; special structures; and on-site supervision or inspection. This code has detailed explanations of the building demolition methods, also includes case studies and figure illustrations; hence this code provides specific reference to the choice of demolition method. Although it just has brief regulations about building environmental factors, it clearly puts forward the idea of reusing or recycling of building debris and wastes which is the current trend of the construction industry.</p>

Chapter VI

Discussion of Building Demolition Code Draft and Suggestions for the Demolition Projection Management

1. Discussion of the Structure of Building Demolition Code

After analyzing the current building demolition code in Taiwan and comparing it with other foreign countries' codes, this study suggests the following structure for the proposed new building demolition code:

Table 15: Structure of Building Demolition Code

Chapter	Contents
Chapter 1 Generals	1.1 Generals 1.2 Scope
Chapter 2 Contract Management	2.1 General Regulations 2.2 Contract Content 2.3 Contract Implantation
Chapter 3 Planning for Demolition Works	3.1 General Regulations 3.2 Building Survey 3.3 Planning for Demolition Project 3.4 Planning for Demolition Method 3.5 Demolition Organization and Personnel Arrangement
Chapter 4 On-site Management	4.1 Project Site Configuration 4.2 Equipments Management 4.3 Check and Supervise during Demolition
Chapter 5 Safety and Accidents Prevention	5.1 Labors Safety Precaution Measures 5.2 Public Bodies' and Properties' Safety 5.3 Accidents Emergency Plan
Chapter 6 Environmental Protection and Waste Disposal	6.1 Environmental Protection 6.2 Waste Disposal

<p style="text-align: center;">Chapter 7</p> <p style="text-align: center;">Traffic Maintenance</p>	<p>7.1 Investigation of Project Traffic Conditions</p> <p>7.2 Public Traffic Maintenance</p> <p>7.3 Project Transportation Organization</p>
<p style="text-align: center;">Chapter 8</p> <p style="text-align: center;">Project Completion</p>	<p>8.1 Works Completion Examination</p>

*: This table is drafted by this research. The RC Building Demolition Code draft has been already formatted and submitted to the Disaster Prevention Division, ABRI, Taiwan. And the draft code was published in Dec. 2006^[3].

2. Suggestions for the Demolition Project Management

The following suggestions and recommendations were proposed to improve the current building demolition practice in Taiwan.

(1) Directly Feasible Suggestions

- i. Before the certain scale building demolition project begins, contractors need to submit a project quality control layout.
- ii. The building demolition project should carry out project information recording systems.
- iii. Government and building owner should organize the work completion check and accepting criteria.
- iv. For the safety of demolition projects, government officials should set up related experts or supervisors checking and endorsing system.

(2) Mid- or Long-Term Recommendations

- i. As for the demolition contractors' classification, the project contracting qualification should be considered by its classification and its specialities.
- ii. The building demolition project supervisor's professional level should be certified.
- iii. For the buildings which have chemicals, toxins, or fire potentials, the fire

department and safety department should join together to conduct the project examination; the project can only carry out with safety plans in-place.

- iv. The safety inspections in the building demolition projects should be encouraged to be regularly performed by the contractors themselves.
- v. The code needs to have more complete measures to deal with wastes, materials, earth produced by the building demolition.
- vi. Drafting or consummating of the demolition code in the future could further consult with foreign countries' pertinent regulations.
- vii. Some projects will build new buildings after completing the demolition job, so the code could specify one more examination after the new building project is finished.

Chapter VII

Conclusions and Recommendations

1. Conclusions

The life cycle of reinforced concrete buildings is usually 40 to 90 years. However, during this cycle, buildings will often meet some circumstances, such as disasters damage, usage change, city reconstruction, or higher demand for the residence etc.; all of these circumstances will lead to the demolition or reconstruction of buildings.

Through the study of the other countries' advanced building demolition management regulations, demolition codes and the comparison of the differences between Taiwan and foreign countries' management systems, this research will suggest the management regulations and demolition code for contractors, consulting company and government departments in Taiwan. The major results from this study are listed below:

- (1) Collected related documents, including relevant building demolition laws, codes, project examination forms, and many other regulations in Europe, America, Australia, Mainland China, Japan, Hong Kong, and Taiwan. Also summarized, analyzed and compared different countries' documents related to demolition of RC buildings;
- (2) Discussed the commonly used RC building demolition methods and working processes for the future reference of project contractors or research institutes;
- (3) Provided suggestions for government about enhancing the common RC building demolition management regulations. Also, these suggestions will help contractors improve their project management abilities;
- (4) Summed up the present ordinances related to the building demolition in Taiwan, and proposed the specific ordinance item modification contents;
- (5) Composed the draft for the Common Reinforced Concrete Building

Demolition Code in Taiwan, including General, Demolition Plans, Safety and Accidents Prevention Measures, On-site Demolition Management, Contracts Management, Traffic Organization, and Waste Disposal & Recycle etc.

2. Recommendations

- (1)** The current trend of demolition/deconstruction research which will have great social and economical benefits needs to be conducted in the future in Taiwan (Appendix A & B);
- (2)** For the steel structure buildings demolition, the related code is also needed in Taiwan;
- (3)** The building implosion demolition regulations and code requirements are needed to be developed in Taiwan and US.
- (4)** In this study, we did not find that US has a common building demolition code like British or New Zealand etc., US may also need to develop a similar code by some institute.
- (5)** The new concept like Design for Deconstruction (DFD) for steel structure etc. is a good topic for the future research.

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APPENDIX A

Current trend of building deconstruction practice in the demolition industry

Deconstruction seeks to maintain the highest possible value for materials in existing buildings by dismantling buildings in a manner that will allow the reuse or efficient recycling of the materials. Deconstruction is emerging as an alternative to demolition in the US and around the world.

Deconstruction is the dismantling of buildings to safely and responsibly maximize the reuse and recycling of building materials in a cost-effective manner. Building material reuse retains valuable energy invested in existing materials, preserves valuable resources, and reduces the pollution associated with the production and disposal of building materials.

The following pictures are showing the deconstruction procedure of the Wesley House, Florida, 2003 ^[26].

Original state of the old house

Interior Finishes Removal

Exterior Walls Disassembly

Roof Structure Removal

Floor Structure Removal

Fig. 15 Building Deconstruction Procedure ^[26]

APPENDIX B

Future research trend in the demolition / deconstruction of steel structures

A review of deconstruction case studies found that the total diversion rate for deconstructed buildings through recycling and reuse ranged from 50% to 90% in year 2000. This represents a reduction in the national waste stream of an estimated 62 to 113 million tons a year. Currently, there are increasing percentages in the recycling of building steel or steel components of buildings.

But right now, there is no specific reference to steel products recovered from existing buildings; the methods of inspection and testing are relevant to either new or existing products. The main steel products used in multi-story construction are hot rolled products referred to BS 4360:1990 and BS EN 10025:1990. These documents specify the mechanical properties for specific grades of steel. They also refer to inspection and testing.

Moreover, according to the research of University of Florida, there are currently no specific national or international standards relating to the disassembly, deconstruction or demolition of steel structures until 2003 ^[27]. Design standards make no reference to the reuse of steel members from demolition of existing buildings ^[27].

However, there are already many cases of demolishing steel structure buildings as shown in the following pictures. Hence, it is necessary to establish standards in the area of demolition and destruction of steel structural buildings.

Fig. 16 Using machine to demolish the steel structure building *

* Picture from: <http://www.aec.bf.umich.edu/projects/palmer/BM%20newsletter/11122000.pdf>

Fig. 17 Hudson Department Store steel structure implosion *

*: Pictures come from the Controlled Demolition, Inc. www.controlled-demolition.com

VITA

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